*The Interplay among Black Holes, Stars and ISM in Galactic Nuclei*
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# Why (inner) bars are important but not sufficient

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**Abstract.** I briefly report on the work conducted to probe the gravitational potential of active and non-active disk galaxies using gas and stellar kinematics.

## 1. Introduction

Bars and non-axisymmetric galactic structures imply time variable torques which can help transfering angular momentum. Large-scale bars are important actors in the spatial redistribution of the dissipative component in disk galaxies, and there is indeed a direct observed link between their presence and e.g. star formation or the gas concentration. However, as repeatedly emphasized by many authors (see e.g. Martini's contribution in these Proceedings), there is no significant correlation between the nuclear activity and the presence of such structures. A nice summary has been given by F. Combes (these Proceedings), but I should start by repeating a simple but important argument.

## 2. Time and space

Before discussing the causality between different physical phenomena, it is first necessary to clearly define what we wish to write about, and to examine if the presumed actors can coexist in time and space. When astronomers write about fuelling a galactic nucleus, they mean the central engine, where most of the high energy radiation originates: close to the central black hole, and well inside a few hundredths of parsec. It is therefore not that surprising if we cannot find direct evidence for a link between such a tiny region and large (few kpc) or medium (few hundred pc) scale structures.

Time is then also a critical parameter. If we just list a few important processes and their corresponding timescales:

- Dynamics: 100 pc corresponds to about $10^6$ yr for a velocity of 100 km/s.
- The duty cycle of nuclear activity is usually quoted with scales of $10^6$ to $10^8$ yr.
- Steady mass accretion: $10^3$ to $10^4$ yr (see Wada, these Proceedings).
- Average fuelling rate: $10^{-3}$ to 1 $M_\odot$/yr (for a total mass processed of $10^3$ to $10^8$ $M_\odot$).
- Star formation has a global timescale of about $10^8$ yr.

If the central activity and the formation of a large-scale bar are reccurent processes (see Combes, these Proceedings), it seems illusory to expect an observed simultaneity (Fig. 1. But as gas is assumed to gradually fall down the gravitational potential of the galaxy, we can proceed in steps, focusing on one specific spatial scale at a time.

## 3. Building a gas reservoir at 1 kpc

The first important step can be taken to be roughly 1 kpc, as it corresponds to e.g. the Inner Lindblad Resonance of large-scale bars where gas can be efficiently accumulated.


**Figure 1.** Sketch showing the wildly different scales we usually deal with when trying to link the nuclear activity with e.g. a large-scale bar. Rs is the Schwarzschild radius of the presumed black hole, $\sim 10^{-5}$ pc for $10^8$ $M_\odot$.

Although the loss of angular momentum is intrinsically a dynamical process, we do not know much about the underlying gravitational potential of disk galaxies.

We thus defined a small sample of nearby early-type disk galaxies with the aim of constraining both their stellar and gas distributions and kinematics. A range of very nearby galaxies with matched active and non-active pairs was carefully selected. For each target we are probing sensitive large-scale tracers, using HI observations, but also more centrally concentrated ones such as the ionized gas and the stellar populations within the central few kpc. The gas and stellar kinematics are derived via integral-field spectroscopy with `SAURON`, a large field unit mounted on the William Herschel telescope.

We expect a number of difficulties to pave our way. We will need to disentangle the gas and stellar contributions in spectra which contain strong and wide emission lines. We also need to interpret the gas and stellar kinematics in a consistent framework using adaptive modelling techniques. NGC 1068 was observed in Jan. 2002 with `SAURON` and used as a technical benchmark in this context. We thus developed an iterative method to properly extract the kinematic information, using synthetic stellar library and a penalized pixel fitting routine to fit the stellar absorption lines (see Cappellari & Emsellem 2004). We also built N body/SPH simulations starting from axisymmetric initial conditions to probe the effect of the observed near-infrared bar on the stellar kinematics. We could thus provide some new constraints on the dynamics, and time variability of the system. Work is in progress and will be published soon (Emsellem *et al.*, in preparation).

We obtained our first `SAURON` observations of active and non-active galaxies in March 2004: the weather has been favourable enough so we could observe 12 targets (6 pairs). The reduction and analysis will be conducted using our dedicated pipeline. The survey will be completed with two runs in the 2004B and 2005A semesters.

## 4. Building a gas reservoir at 100 pc

Zooming towards the center, at a scale of about 100 pc, we are still quite far from the direct influence of the presumed supermassive black hole: for a typical stellar velocity dispersion of 150 km/s, the radius of influence is only $r_h = 2(M_\bullet/10^7\ M_\odot)$ pc. In order to build a gas reservoir inside $\sim$ 100 pc (not invoking mergers), we could think of inner density waves such as secondary bars, central spirals or $m = 1$ modes.

Inner bars are present in at least 25% of all barred galaxies (Erwin et al. 04, Erwin and Sparke 2002), and this represents more than 15% of all disk galaxies. Another 20% of galaxies contain inner disks, which may also be related to fuelling episodes (see e.g. van den Bosch & Emsellem 1998). Secondary bar sizes range from 200 to 800 pc (Erwin et al. 04) which means that the corresponding (presumed) Inner Lindblad Resonances should be well within the central 100 pc.

The above-mentioned fraction of galaxies containing innner bars is of course a lower

limit as such structures are not easily detected. Studies have so far focused on photometric and dust features, but our specific study of NGC 2974 has shown that these could be misleading (Emsellem, Goudfrooij, Ferruit, 2003), hence weak bars could easily be hidden by the central spheroidal component. We believe that the best tracers include the stellar and gas distribution and kinematics, and that again only their detailed mapping can reveal the nature of the underlying potential.

This is clear when looking at cases like NGC 1358, NGC 3504 with an integral-field spectrograph such as OASIS. The two-dimensional gas distribution and kinematics shows highly non-circular motions with the inner bar and/or $m = 1$ structures leading to significant inward motion. Unfortunately, it is sometimes difficult (or impossible) to disentangle the contribution of the AGN (outflow, nuclear emission) from the gravitational motion.

## 5. The formation and evolution of $\sigma$–drops

This is nicely illustrated in the case of NGC 5728, where OASIS observations show bar-driven kinematics on one side of the nucleus, and strong AGN-driven outflow on the other side. In this case, we need to probe the stellar component which is expected to be less prone to non-gravitational motions. We obtained VLT/ISAAC long-slit data in the central few arcseconds of NGC 5728 and derived the stellar kinematics along the major and minor axes of the inner bar (Emsellem et al. 2001). These revealed a clear velocity decoupling of the central arcsecond, ($\sim 150$ *pc*). More interestingly, the stellar velocity dispersion profile exhibits a significant drop in the same region. These so-called $\sigma$–drop were in fact observed in 3 out of 3 galaxies for which we could probe the central kinematics. $\sigma$–drops are now almost routinely observed in disk galaxies (e.g. Marquez et al. 2003), and a non-exhaustive list is provided in Fig. 2. It is important to emphazise that such drops require high signal-to-noise spectra with reasonable spatial resolution, and that data of this type are scarce for disk galaxies.

We have studied a possible scenario for the formation of $\sigma$–drops via N body + SPH simulations including star formation (Wozniak et al. 2003). A decrease in the stellar velocity dispersion requires the presence of a dynamically cold component, which we assume is formed via bar-driven gas infall and subsequent star formation. This scenario is nicely supported by the numerical simulations which exhibits long-lived $\sigma$–drops. The new-born stars form out of very low dispersion gas, and the $\sigma$–drop appears where the young stellar disk significantly contributes to the luminosity. The whole central stellar system, not just the disk, will heat up with time, allowing the $\sigma$–drop to stay visible for hundreds of Myr. We should emphasize that this is however not a unique scenario, and any process which can efficiently tranport gas within the central few hundreds parcsec is a good candidate for the formation of $\sigma$–drops.

## 6. Conclusions

I will conclude by reiterating on a few important issues. First stating once more that building a gas reservoir within the central 1 kpc or 100 pc, is a different thing than fuelling the central engine: spatial and time scales are important in this context. Hence we should make it clear when we write about "fuelling the AGN".

In this short paper, I focused on the accumulation of gas first within the central 1000 and 100 pc. Our `SAURON` survey of active and non-active galaxies, supplemented by large-scale HI data, will provide us with a unique probe of the underlying gravitational potential in the inner kpc. Inside this region, inner bars are not rare and may indeed play an important role in accumulating mass within the central 100 pc. However, we need

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|---|---|---|---|
| NGC 1097 | SB(s)b | Sy2 | **Emsellem et al. 2001** |
| NGC 1138 | SBO | ? | Simien & Prugniel 2002 |
| NGC 1808 | SAB(s:)b | Sy 2/starburst | **Emsellem et al. 2001** |
| NGC 2460 | SAa | ? | Shapiro et al. 2003 |
| NGC 2775 | SAab | ? | Shapiro et al. 2003 |
| NGC 4030 | SAbc | ? | Shapiro et al. 2003 |
| NGC 2639 | SA(r)a | Sy 1.9 | **Marquez et al. 2003** |
| NGC 3412 | SB0(s) | ? | Aguerri et al. 2003 |
| NGC 3593 | SA(s)0/a | Sy 2 | Bertola et al. 1993 |
| NGC 3623 | SAB(rs)a | Liner | De Zeeuw et al. 2002 |
| NGC 3627 | SBb | Liner/Sy 2 | Héraudeau & Simien 1998 |
| NGC 4303 | SBbc | Sy 2 | Héraudeau & Simien 1998 |
| NGC 4579 | SBb | Liner/Sy 1.9 | Héraudeau & Simien 1998 |
| NGC 4725 | SBab | Sy 2 | Héraudeau et al. 1999 |
| NGC 4477 | SB0 | Sy 2 | Jarvis et al. 1988 |
| NGC 5728 | SABb(r) | Sy 2 | **Emsellem et al. 2001** |
| NGC 6503 | SA(s)cd | Liner/HII | **Bottema 1993; Bottema & Gerritsen 1997** |
| NGC 6814 | SAB(rs)bc | Sy 1.5 | **Marquez et al. 2003** |
| NGC 6951 | SAB(rs)bc | Sy 2 | **Marquez et al. 2003** |
| IC 184 | SB(r)a | Sy 2 | **Marquez et al. 2003** |

**Figure 2.** Non-exhaustive list of galaxies with observed $\sigma$–drops. From left to right: galaxy name, type, activity if known, and associated reference.

to map both gas and stellar kinematics in order to reveal the dynamical structures. We may then find that $\sigma$–drops are long-lived signatures of accretion, but this will require to extend the available pool of data quite dramatically.

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